

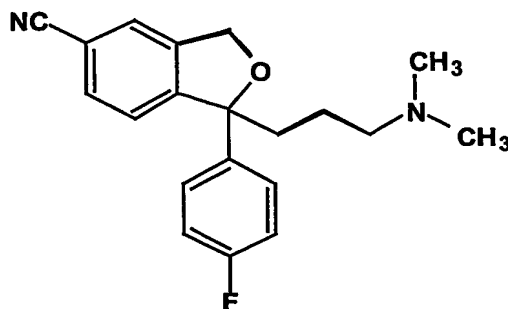
A process for the preparation of racemic citalopram diol and/or *S*- or *R*-citalopram diols and the use of such diols for the preparation of racemic citalopram, *R*-citalopram and/or *S*-citalopram

5 The invention relates to a process for the preparation of racemic citalopram diol and *R*- or *S*-citalopram diol by separating an initial non-racemic mixture of the compounds *R*- and *S*-citalopram diol (*R*- and *S*-4-[4-(dimethylamino)-1-(4'-fluorophenyl)-1-hydroxybutyl]-3-(hydroxymethyl)-benzonitrile) into a fraction of racemic citalopram diol and a fraction being enriched with *S*-diol or *R*-diol. The invention also relates to
10 the use of such isolated citalopram diols for the formation of the corresponding racemic citalopram and/or *S*- or *R*-citalopram to be comprised in a pharmaceutical composition.

Background of the invention

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Citalopram is a well-known antidepressant drug that has now been on the market for some years and has the following structure:



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Citalopram may be prepared by ring closure of 4-[4-(dimethylamino)-1-(4'-fluorophenyl)-1-hydroxybutyl]-3-(hydroxymethyl)-benzonitrile (racemic citalopram diol) as described in US patent No. 4,650,884. The product citalopram is a racemic
25 mixture of the *R*- and *S*-enantiomers.

Further, the *S*-enantiomer of citalopram (escitalopram) is a valuable antidepressant of the selective serotonin reuptake inhibitor (SSRI) type. Escitalopram may be prepared

by ring closure of *S*-4-[4-(dimethylamino)-1-(4'-fluorophenyl)-1-hydroxybutyl]-3-(hydroxymethyl)-benzonitrile (*S*-diol) with retention of configuration as described in EP B1 347 066. The amount of *R*-citalopram compared to *S*-citalopram in the product escitalopram should be less than 3%.

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Furthermore, a method for the preparation of a mixture of *R*- and *S*-citalopram with more than 50% of the *S*-enantiomer from a mixture of *R*- and *S*-diol with more than 50% of the *R*-diol is described in WO03000672.

- 10 It appears from the above, that products of racemic citalopram and escitalopram with the above-mentioned enantiomeric purity are required for the preparation of pharmaceutical compositions and that racemic citalopram and escitalopram products may be prepared by ring closure of the *RS*-diol and *R*-diol and/or *S*-diol. As a consequence, methods for the preparation of products of racemic diol and *S*-diol being
15 correspondingly enantiomerically pure are required.

- Processes for the preparation and purification of *R*- or *S*-diol products are available. Such processes involve for instance enantio-selective synthesis as described in EP 0347066, classical resolution and chromatographic separation as described in
20 WO03006449. Depending on the specific process and the conditions used, the enantiomeric purity of the *S*-diol product may have to be improved before the *S*-diol product will meet the above requirements.

- Surprisingly, it has now been found that by using the process of the invention an
25 expensive, but apparently useless *S*-diol product being contaminated with *R*-diol, may easily be converted into the two valuable products, racemic diol and *S*-diol, which meet the above requirements as regards enantiomeric purity.

- Furthermore, by using the process of the invention, an expensive, but apparently
30 useless *R*-diol product being contaminated with *S*-diol, may easily be converted into the valuable products, racemic diol and *R*-diol, which meet the above requirements as regards enantiomeric purity.

More particularly, the present invention provides a process for the separation of an initial non-racemic mixture of *R*- and *S*-4-[4-(dimethylamino)-1-(4'-fluorophenyl)-1-hydroxybutyl]-3-(hydroxymethyl)-benzonitrile with more than 50% of one of the enantiomers into a fraction being enriched with *S*-diol or *R*-diol and a fraction
5 comprising *RS*-diol, wherein the ratio of *R*-diol:*S*-diol is equal to 1:1 or closer to 1:1 than in the initial mixture of *R*- and *S*-diol.

The process of the invention is important and very useful, in particular because it provides a convenient, cheap and efficient way to transform a mixture of *R*- and *S*-
10 diols which does not meet the above requirements as regards enantiomeric purity into two valuable products, *RS*-diol and *S*-diol (or *R*-diol), which meet the above requirements as regards enantiomeric purity.

In another aspect, the invention provides a convenient, cheap and efficient method for
15 making an intermediate to be used in the manufacturing of citalopram and escitalopram.

With the present invention, the process for the production of racemic citalopram and escitalopram meeting the requirements of the respective marketing approvals has
20 become more rational and more economical as regards the simplicity of the process and the utilisation of reagents and resources.

Summary of the Invention

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Thus, the present invention relates to a process for the preparation of racemic diol free base and/or acid addition salt and/or *R*- or *S*-diol free base and/or an acid addition salt comprising a separation of an initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt with more than 50% of one of the enantiomers into a fraction
30 being enriched with *S*-diol or *R*-diol free base and/or acid addition salt and a fraction comprising *RS*-diol free base and/or acid addition salt wherein the ratio of *R*-diol:*S*-diol is equal to 1:1 or closer to 1:1 than in the initial mixture of *R*- and *S*-diol wherein

- i) *RS*-diol free base and/or acid addition salt is precipitated from a solution of the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt; or
5 *R*- or *S*-diol free base and/or acid addition salt is dissolved into a solvent from the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt in said solvent, leaving a residue comprising *RS*-diol free base and/or acid addition salt;
- ii) the residue/precipitate formed is separated from the final solution
10 phase;
- iia) if the residue/precipitate is crystalline it is optionally recrystallised one or more times to form racemic diol;
- iib) if the residue/precipitate is not crystalline, steps i) and ii) are
15 optionally repeated until a crystalline residue/precipitate is obtained and the crystalline residue/precipitate is optionally recrystallised one or more times to form racemic diol;
- iii) the final solution phase is optionally subjected to further purification
20 and *S*-diol or *R*-diol free base and/or acid addition salt is isolated from the final solution phase;
- iv) the free bases of the diols obtained are optionally converted to acid
25 addition salts thereof or acid addition salts of the diols obtained are optionally converted to other acid addition salts or acid addition salts of the diols obtained are optionally converted to the corresponding free bases.
- 30 Accordingly, the *RS*-diol free base and/or acid addition salt obtained gives rise to the final solution phase being enriched with either the *S*- or *R*-diol free base and/or acid addition salt. The surplus of *R*- or *S*-diol free base and/or acid addition salt may then be isolated from the final solution phase as described below.

According to a specific embodiment, the invention relates to a process for the preparation of racemic diol free base and/or acid addition salt using the process described above.

- 5 According to another specific embodiment, the invention relates to a process for the preparation of *S*-diol (or *R*-diol) free base and/or an acid addition salt using the process described above.

- 10 According to still another specific embodiment, the invention relates to the use of the prepared racemic diol free base and/or acid addition salt and/or *S*-diol (or *R*-diol) free base and/or an acid addition salt for the preparation of racemic citalopram and/or *S*-citalopram (or *R*-citalopram) free base and/or acid addition salt using the process described below.

15 **Detailed description of the invention**

Whenever used in this document, the terms "*S*-diol" and "*S*-citalopram diol" mean *S*-4-[4-(dimethylamino)-1-(4-fluorophenyl)-1-hydroxybutyl]-3-(hydroxymethyl) benzonitrile.

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Whenever used in this document, the terms "*R*-diol" and "*R*-citalopram diol" mean *R*-4-[4-(dimethylamino)-1-(4-fluorophenyl)-1-hydroxybutyl]-3-(hydroxymethyl) benzonitrile.

- 25 Whenever used in this document, the term "*RS*-diol" means a mixture of *R*- and *S*-diol such as a 0.5:1.5 or 0.9:1.1 or 0.95:1.05 or 0.98:1.02 or 0.99:1.01 mixture of *R*- and *S*-diol and preferably a mixture with a 1:1 ratio of the *R*- and *S*-diol.

- 30 Whenever used in this document, the terms "diol enantiomer" and "diol isomer" mean either *S*- or *R*-diol.

Whenever used in this document, the term "racemic diol" means a 1:1 mixture of the *R*- and *S*-diols. The term "non-racemic mixtures of diols" means mixtures which contain *R*- and *S*-diols in a ratio other than 1:1.

- 5 Whenever used in this document, the terms "citalopram enantiomer" and "citalopram isomer" mean either *S*- or *R*-citalopram.

Whenever used in this document, the term "racemic citalopram" means a 1:1 mixture of *R*- and *S*-citalopram. The term "non-racemic citalopram" means mixtures which
10 contain *R*- and *S*-citalopram in a ratio other than 1:1.

As used in this description, the term "precipitation" means forming a precipitate, in the form of crystals, an amorphous solid or an oil or mixtures thereof, from a solution of the initial non-racemic mixture of *R*- and *S*-diol in a solvent. In the present
15 description, a precipitate may be an oil, an amorphous solid or crystals or mixtures thereof.

As used in this description, the term "residue" refers to the residue remaining after dissolving *R*- or *S*-diol into a solvent from an initial non-racemic mixture of *R*- or *S*-
20 diols. The residue may be in the form of crystals, an amorphous solid or an oil or mixtures thereof.

As used herein, the term "residue/precipitate" refers to either a precipitate or a residue as defined above.
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As used herein, the term "mother liquor" means the solvent remaining after removal or separation from the precipitate.

As used herein, the term "organic and/or aqueous phase resulting from the selective
30 dissolution of *R*- or *S*-diol" refers to the phase wherein *R*- or *S*-diol is dissolved from an initial non-racemic mixture of *R*- or *S*-diols.

As used herein, the term "final solution phase" refers to a mother liquor or an organic and/or aqueous phase resulting from the selective dissolution of *R*- or *S*-diol as defined above.

5 As already mentioned, the above processes for the preparation of citalopram free base and/or acid addition salt and/or escitalopram free base and/or acid addition salt may result in a mixture of *R*- and *S*-citalopram free base and/or acid addition salt which is not acceptable for pharmaceutical use. According to the present invention, a surprisingly efficient process for the preparation of racemic diol and *R*- or *S*-diol free
10 base and/or acid addition salt to be used for the preparation of racemic citalopram free base and/or acid addition salt and *R*- or *S*-citalopram free base and/or acid addition salt has been found.

This new process involves the separation of an initial non-racemic mixture of *R*- and
15 *S*-diol free base and/or acid addition salt into a fraction of racemic diol free base and/or acid addition salt and a fraction of *R*- or *S*-diol free base and/or acid addition salt. The fraction of racemic diol free base and/or acid addition salt is precipitated as an oil, an amorphous solid or in crystalline form or mixtures thereof from a solvent, and the *R*- or *S*-diol free base and/or acid addition salt is isolated from the final
20 solution phase. Then, racemic citalopram free base and/or acid addition salt and *R*- or *S*-citalopram free base and/or acid addition salt may be formed from the corresponding racemic diol free base and/or acid addition salt and *R*- or *S*-diol free base and/or acid addition salt by ring closure.

25 According to another aspect of the invention, the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt is separated into a fraction being enriched with *S*-diol or *R*-diol free base and/or acid addition salt and a fraction comprising *RS*-diol free base and/or acid addition salt wherein the ratio of *R*-diol:*S*-diol is equal to 1:1 or closer to 1:1 than in the initial mixture of *R*- and *S*-diol by
30 mixing the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt with a solvent and allowing preferentially the *R*- or *S*-diol free base and/or acid addition salt to dissolve in the solvent followed by separation of the undissolved *RS*-diol free base and/or acid addition salt residue from the organic and/or aqueous phase

resulting from the selective dissolution of *R*- or *S*-diol free base and/or acid addition salt and isolation of *R*- and *S*-diol free base and/or acid addition salt from said solvent.

- 5 The solvent used according to this embodiment of the invention is any solvent which allow preferentially the *R*-or *S*-diol free base and/or acid addition salt to dissolve leaving a mixture of *RS*-diol free base and/or an acid addition salt wherein the ratio of *R*-diol:*S*-diol is equal to 1:1 or closer to 1:1 than in the initial mixture of *R*- and *S*-diol as a residue. Useful solvents are solvents such as those mentioned for the precipitation
10 of *RS*-diol free base and/or *RS*-diol acid addition salts.

The initial non-racemic mixture of *R*- and *S*- diol free base and/or acid addition salt used in the process of the invention may be an oil, an amorphous solid or in
15 crystalline form; or mixtures thereof.

The residue/precipitate formed in step i) may be an oil, an amorphous solid or in crystalline form; or a mixture thereof. The residue/precipitate formed in step i) is preferably in crystalline form.

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According to one embodiment of the invention, the initial non-racemic mixture of *R*- and *S*- diol free base and/or acid addition salt used in the process of the invention contains more than 50% of *S*-diol, or more preferred more than 70% of *S*-diol or most preferred more than 90% of *S*-diol.

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According to another embodiment of the invention, the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt used in the process of the invention contains less than 99.9% of *S*-diol, such as less than 99.5% of *S*-diol, or less than 99% *S*-diol, or less than 98% of *S*-diol.

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Accordingly, the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt may contain 50%-98% of *S*-diol, or 50%-99% of *S*-diol, or 50%-99.5% of *S*-diol, or 50%-99.9% of *S*-diol, or 70%-98% of *S*-diol, or 70%-99% of *S*-diol, or

70%-99.5% of *S*-diol, or 70%-99.9% of *S*-diol, or 90%-98% of *S*-diol, or 90%-99% of *S*-diol, or 90%-99.5% of *S*-diol, or 90%-99.9% of *S*-diol.

5 According to another embodiment of the invention, the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt used in the process of the invention contains more than 50% of *R*-diol, or more preferred more than 70% of *R*-diol or most preferred more than 90% of *R*-diol.

10 According to yet another embodiment of the invention, the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt used in the process of the invention contains less than 99.9% of *R*-diol, such as less than 99.5% of *R*-diol, or less than 99% *R*-diol, or less than 98% of *R*-diol.

15 Accordingly, the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt may contain 50%-98% of *R*-diol, or 50%-99% of *R*-diol, or 50%-99.5% of *R*-diol, or 50%-99.9% of *R*-diol, or 70%-98% of *R*-diol, or 70%-99% of *R*-diol, or 70%-99.5% of *R*-diol, or 70%-99.9% of *R*-diol, or 90%-98% of *R*-diol, or 90%-99% of *R*-diol, or 90%-99.5% of *R*-diol, or 90%-99.9% of *R*-diol.

20 The process may be repeated until a racemic mixture of *R*- and *S*-diols is obtained and/or until the desired degree of enantiomeric purity of the *R*- or *S*-diol is obtained.

25 According to one embodiment of the invention, the *RS*-diol of the residue/precipitate is in the form of a free base and/or an acid addition salt; and independently thereof the *R*- or *S*-diol of the final solution phase is in the form of a free base and/or an acid addition salt. Accordingly, when the *RS*-diol comprised in the residue/precipitate is in the form of a free base, then the *R*- or *S*-diol comprised in the final solution phase, may be in the form of a free base, an acid addition salt or a mixture of a free base and an acid addition salt. Furthermore, when the *RS*-diol comprised in the
30 residue/precipitate is in the form of an acid addition salt, then the *R*- or *S*-diol comprised in the final solution phase, may be in the form of a free base, an acid addition salt or a mixture of a free base and acid addition salt. Finally, when the *RS*-diol comprised in the residue/precipitate is a mixture of a free base and an acid

addition salt, then the *R*- or *S*-diol comprised in the final solution phase, may be in the form of a free base, an acid addition salt or a mixture of a free base and acid addition salt.

- 5 The initial non-racemic mixture of *R*- and *S*- diol used in the process of the invention may be present as the free base, as salts, or as a mixture of free bases and salts.

Furthermore, the free bases of the diols obtained are optionally converted to acid addition salts thereof or acid addition salts of the diols obtained are optionally
10 converted to other acid addition salts or acid addition salts of the diols obtained are optionally converted to the corresponding free bases by methods known to those skilled in the art.

- 15 Precipitation of the *RS*-diol free base may be carried out by obtaining or dissolving the non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt in a suitable solvent, optionally by applying heat, and then allowing the solution to cool, or by cooling to below ambient temperature. The precipitate is then separated from the mother liquor, preferably by filtration or decanting.

20 A residue of *RS*-diol free base may be formed by selective dissolution of *R*- or *S*-diol free base and/or acid addition salt into a solvent from the initial non-racemic mixture of *R*- and *S*-diols free base and/or acid addition salt in said solvent. The residue is then separated from the organic and/or aqueous phase resulting from the selective
25 dissolution of *R*- or *S*-diol.

If the residue/precipitate is crystalline, the crystals are optionally recrystallised one or more times to form racemic diol free base. Then, racemic citalopram free base may be formed from the racemic diol free base by ring closure. The free base of racemic
30 citalopram may optionally be converted to an acid addition salt thereof, preferably the hydrobromide salt.

If the residue/precipitate formed is an oil or an amorphous solid, steps i) and ii) may be repeated until a crystalline product is obtained. The crystals obtained are optionally recrystallised one or more times to form racemic diol free base. Racemic citalopram free base may be formed from the racemic diol free base by ring closure.

- 5 The free base of racemic citalopram is optionally converted to an acid addition salt thereof, preferably the hydrobromide salt.

The *RS*-diol free base prepared according to the invention is optionally converted to acid addition salts thereof.

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An oily phase separated from the final solution phase is optionally subjected to conventional purification processes.

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The *RS*-diol free base prepared according to the invention may contain a minor excess of the *S*-diol (or *R*-diol). It may thus be necessary to repeat steps i) and ii) (in particular crystallisation) of the *RS*-diol free base one or more times in order to obtain racemic diol. The final solution phases may be pooled together and the diol enantiomer contained herein may be isolated as described below.

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Suitable solvents for obtaining the residue/precipitate comprising the *RS*-diol free base are apolar solvents for example alkanes, such as heptane or hexane, aromatic hydrocarbons such as toluene, benzene and xylene, polar solvents such as acetonitrile, alcohols such as methanol and iso-propylalcohol or ketones such as methyl isobutyl ketone; or mixtures thereof.

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In a preferred embodiment, a free base of the *RS*-diol is obtained in step i), preferably in crystalline form.

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If necessary, crystallisation may be initiated by seeding with racemic crystalline diol free base.

The precipitation of *RS*-diol acid addition salt may be carried out by obtaining or dissolving the non-racemic mixture of *R*- and *S*-diol free base or acid addition salt in a suitable solvent, if necessary by applying heat, and adding an acid, for example as a solid, a liquid, in a solution or as a gas.

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The acid used for the precipitation of a *RS*-diol acid addition salt is an acid which precipitates a mixture of *R*- and *S*-enantiomers and leaves the mother liquor enriched with either the *R*- or *S*-diol enantiomer of the diol as the free base or an acid addition salt.

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The acid used for the precipitation of a *RS*-diol acid addition salt may be:

- added after the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt is obtained or dissolved in a suitable solvent; and/or
- present in the solvent during and/or prior to dissolution of the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt; and/or
- present in the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt during and/or prior to dissolution in the solvent.

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A residue of *RS*-diol acid addition salt may be formed by selective dissolution of *R*- or *S*-diol free base and/or acid addition salt into a solvent from the initial non-racemic mixture of *R*- and *S*-diols free base and/or acid addition salt in said solvent, if necessary by adding an acid, for example as a solid, a liquid, in a solution or as a gas; or mixtures thereof.

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The acidic part of a *RS*-diol acid addition salt of the residue formed in step i) is an acid, which allows the selective dissolution of either *R*- or *S*-diol free base and/or acid addition salt and leaves the undissolved material enriched with the *RS*-diol acid addition salt.

30

The acid used for forming the *RS*-diol acid addition salt of the residue may be:

- present in the solvent before the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt is mixed with the solvent; and/or
 - mixed with the solvent together with the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt; and/or
 - 5 • mixed with the solvent after the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt is mixed with the solvent; and/or
 - present in the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt during and/or prior to the mixing with the solvent.
- 10 Suitable acids for the formation of a residue/precipitate of *RS*-diol acid addition salt from an initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt are inorganic acids such as hydrochloric acid, hydrobromic acid and sulphuric acid or organic acids such as oxalic acid, *p*-toluenesulfonic acid, methanesulfonic acid and acetic acid. Hydrobromic acid, hydrochloric acid and oxalic acid are preferred
- 15 acids. When these acids are used, a hydrobromide salt, hydrochloride salt or oxalate salt of the *RS*-diol is formed, preferably in crystalline form. Suitably, up to 10 equivalents of acid is used. Accordingly:
- 0.2-10 mol of acid may be used, such as 0.2-0.4 mol, or 0.4-0.6 mol, or 0.9-1.1 mol or 1.8-2.2 mol of acid is used for each mol of *S*- and *R*-diol comprised in
 - 20 the initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt; and/or
 - 0.3-4.0 mol, such as 0.4-0.6 mol, or 0.9-1.1 mol or 1.8-2.2 mol of acid is used for each mol of *RS*-diol comprised in the residue/precipitate.
- 25 In order to increase the ionic strength of the solution, salts such as NaCl may be added to the solution before, during or after the *RS*-diol acid addition salt is obtained in step i). Those skilled in the art will know how to adjust the amount of salt added to obtain the desired effect.
- 30 Suitable solvents for the formation of a residue/precipitate of *RS*-diol acid addition salt from an initial non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt are polar and apolar solvents such as toluene, ethyl acetate, diethylether,

THF, alcohols such as *iso*-propylalcohol, acetonitrile, and ketones such as acetone and methyl isobutyl ketone, and water.

If the residue/precipitate formed in step i) is crystalline, the crystals are separated
5 from the final solution phase, preferably by filtration or decanting. The crystals are optionally recrystallised by dissolving the crystals in a solvent, preferably by heating, and allowing the solution to cool, or by cooling to below ambient temperature. Racemic citalopram may be formed from the crystalline racemic diol acid addition salt by ring closure. The racemic citalopram may be converted to a pharmaceutically
10 acceptable salt thereof, preferably the HBr salt.

If the residue/precipitate formed in step i) is not crystalline, but amorphous or an oil, or mixtures thereof, steps i) and ii) may be repeated until a crystalline product is obtained. The crystals obtained are optionally recrystallised one or more times as
15 described above. Racemic citalopram may be formed from the crystalline racemic diol acid addition salt by ring closure. The racemic citalopram may be converted into a pharmaceutically acceptable salt thereof, preferably the HBr salt.

An oily phase separated from the final solution phase is optionally subjected to
20 conventional purification processes.

Thus, the *RS*-diol acid addition salt prepared according to the invention may contain a minor excess of the *S*-diol (or *R*-diol). It may thus be necessary to repeat precipitation (in particular crystallisation) of the *RS*-diol acid addition salt one or more times in
25 order to obtain a racemic mixture. The final solution phase may be pooled together and the diol enantiomer contained herein may be isolated as described below.

If necessary, crystallisation of the *RS*-diol acid addition salt may be initiated by seeding with the racemic crystalline diol acid addition salt.
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The *RS*-diol acid addition salt prepared according to the invention is optionally converted into other acid addition salts or the corresponding free base.

According to a preferred embodiment of the invention, a free base of the *RS*-diol or a hydrochloride salt, hydrobromide salt or oxalate salt of the *RS*-diol is obtained, preferably in crystalline form in steps i), iia) and iib).

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The final solution phase, extracts thereof, or a phase enriched with *R*- or *S*-diol free base and/or acid addition salt may be subjected to conventional purification processes (such as treatment with active carbon, chromatography etc.) before evaporation of the solvent, and/or it may be subjected to one or more further precipitations of *RS*-diol free base or *RS*-diol acid addition salt according to the invention, in order to improve the enantiomeric purity of the diol enantiomer product.

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The *R*- or *S*-diol free base and/or acid addition salt may be isolated from the final solution phase using conventional procedures such as evaporation of the solvent, or in case the final solution phase is acidic by basification followed by separation of phases or by extraction of *R*- or *S*-diol free base and/or acid addition salt followed by evaporation of the solvent.

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The final solution phase, extracts thereof, or a phase enriched with *R*- or *S*-diol free base and/or acid addition salt may be subjected to conventional purification processes (such as treatment with active carbon, chromatography etc.) before the isolation from the *R*- or *S*-diol free base and/or acid addition salts. Suitably, *R*- or *S*-diol may be precipitated as a phosphate salt or an oxalate salt by methods known to those skilled in the art.

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It has been found that the enantiomeric purity (the ratio between the wanted isomer and the sum of both isomers) of the *S*- or *R*-diol free base and/or acid addition salt left in the final solution phase may be as high as 97-98% or even higher (i.e. better) depending on the specific conditions used.

25

Accordingly, the *S*-diol (or *R*-diol) free base and/or acid addition salt prepared according to the invention may contain a minor amount of the *R*-diol (or *S*-diol) free base and/or acid addition salt. In one embodiment this minor amount may be less than

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3%, or more preferred less than 2%, or most preferred less than 1% (the ratio between the isomer contained in a minor amount and the sum of both isomers).

The *R*- or *S*-diol free base and/or acid addition salt may be purified and isolated from
5 said solvent or final solution phase as described above.

In one embodiment, *R*-diol free base or acid addition salt is obtained.

10 In another embodiment, *S*-diol free base or acid addition salt is obtained.

When *R*- or *S*-diol free base is obtained, it is optionally converted to acid addition salts thereof. When *R*- or *S*-diol acid addition salt is obtained, it is optionally converted to other acid addition salts or to the corresponding free base.

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Enantiomerically-pure *R*- or *S*-diol free base and/or acid addition salt may be mixed with a non-racemic mixture of *R*- and *S*-diol free base and/or acid addition salt to obtain racemic diol free base and/or acid addition salt. Racemic diol free base and/or
20 acid addition salt may then be obtained by one or more precipitations of racemic diol free base and/or an acid addition salt thereof, followed by recrystallisation as described above.

R- or *S*-citalopram free base and/or acid addition salt may be formed from the
25 corresponding *R*- or *S*-diol free base and/or acid addition salt by ring closure with retention of configuration. *S*-citalopram (or *R*-citalopram) free base and/or acid addition salt may optionally be converted to an acid addition salt thereof, preferably the oxalate salt and optionally recrystallised.

30 Ring closure of the *R*- or *S*-diol free base and/or acid addition salt may be performed via a labile ester intermediate, e.g. in the presence of tosyl-chloride, in a basic environment, as described in EP-B1-347 066. Then, the ring closing reaction proceeds with retention of the stereochemistry. *R*- or *S*-citalopram free base and/or acid

addition salt of an enantiomeric purity substantially equal to the starting diol is then obtained.

5 Ring closure of the obtained racemic diol free base and/or acid addition salt may be performed in an acidic environment, as described in US 4,650,884, or via a labile ester as described above. Thereby, racemic citalopram is obtained.

10 The thus-obtained enantiomerically-pure *R*- or *S*-citalopram free base and/or acid addition salt may be mixed with a non-racemic mixture of *R*- and *S*-citalopram free base and/or acid addition salt to obtain racemic citalopram free base and/or acid addition salt. Racemic citalopram free base and/or acid addition salt may then be obtained by one or more precipitations of citalopram free base or an acid addition salt thereof, followed by recrystallisation as described above.

15

One particular embodiment of the invention relates to a process for the preparation of racemic diol free base or an acid addition salt thereof and/or *R*- or *S*-diol as the free base or an acid addition salt thereof by the separation of an initial non-racemic mixture of *R*- and *S*-diol with more than 50% of one of the enantiomers into a fraction
20 being enriched with *S*-diol or *R*-diol and a fraction consisting of *RS*-diol wherein the ratio of *R*-diol:*S*-diol is equal to 1:1 or closer to 1:1 than in the initial mixture of *R*- and *S*-diol wherein

25

i) *RS*-diol is precipitated from a solvent as the free base or as an acid addition salt thereof;

ii) the precipitate formed is separated from the mother liquor;

30

iiia) if the precipitate is crystalline it is optionally recrystallised one or more times to form racemic diol;

iiib) if the precipitate is not crystalline, steps i) and ii) are optionally repeated until a crystalline precipitate is obtained and the

crystalline precipitate is optionally recrystallised one or more times to form racemic diol;

5 iii) the mother liquor is optionally subjected to further purification and *S*-diol or *R*-diol is isolated from the mother liquor;

10 iv) the free bases of the diols obtained are optionally converted to acid addition salts thereof or acid addition salts of the diols obtained are optionally converted to other acid addition salts or acid addition salts of the diols obtained are optionally converted to the corresponding free bases.

15 Another particular embodiment of the invention relates to a process for the preparation of racemic diol free base or an acid addition salt thereof and/or *R*- or *S*-diol as the free base or an acid addition salt thereof by the separation of an initial non-racemic mixture of *R*- and *S*-diol with more than 50% of one of the enantiomers into a fraction being enriched with *S*-diol or *R*-diol and a fraction consisting of *RS*-diol wherein the ratio of *R*-diol:*S*-diol is equal to 1:1 or closer to 1:1 than in the initial mixture of *R*- and *S*-diol wherein

20 i) *RS*-diol is precipitated from a solvent as the free base or as an acid addition salt thereof; or
25 *R*- or *S*-diol is dissolved into a solvent from the initial non-racemic mixture of *R*- or *S*-diols as the free base or as an acid addition salt thereof in said solvent, leaving a residue;

 ii) the precipitate formed is separated from the mother liquor;

30 iia) if the precipitate is crystalline it is optionally recrystallised one or more times to form racemic diol;

ii b) if the precipitate is not crystalline, steps i) and ii) are optionally repeated until a crystalline precipitate is obtained and the crystalline precipitate is optionally recrystallised one or more times to form racemic diol;

5

iii) the mother liquor is optionally subjected to further purification and *S*-diol or *R*-diol is isolated from the mother liquor;

10

iv) the free bases of the diols obtained are optionally converted to acid addition salts thereof or acid addition salts of the diols obtained are optionally converted to other acid addition salts or acid addition salts of the diols obtained are optionally converted to the corresponding free bases.

15

The invention is illustrated by the following examples, which may not be construed as limiting.

Examples

20 In the following examples optical purities were measured by Chiral SCFC (super critical fluid chromatography) HPLC.

Example 1

25 Purification of *S*-diol by precipitation of racemic diol as the hydrochloride salt

General method:

A mixture of *R*- and *S*-diols (as defined in the table below) (10 g) was dissolved in toluene (60 mL). Aqueous hydrochloric acid solution (32 mL, 1 M) was added, and in
30 some cases solid sodium chloride was added (enough so that the concentration of NaCl in the water was approximately 1 M). The mixture was stirred overnight, and filtered. The residue was dried to give crystals of racemic diol hydrochloride, contaminated by some *S*-diol hydrochloride. The mother liquor was basified with

aqueous ammonia solution to pH > 9, and the toluene layer was separated. The aqueous layer was washed once more with toluene, and the combined toluene extracts were dried over magnesium sulfate and evaporated under reduced pressure to give mainly *S*-diol, contaminated with a small amount of *R*-diol. See table for details.

- 5 Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

Before Precipitation		After Precipitation			
Mixture of Isomers		Precipitate (mixture of R and <i>S</i> -diols)		Oil after basification, separation and evaporation (enriched <i>S</i> -enantiomer)	
S%	R%	S%	R%	S%	R%
98.4	1.6	54	46	97.9	2.1*
95.4	4.6	55	45	98.7	1.3*
90.3	9.7	51	49	96.7	3.3
80	20	51	49	96.7	3.3
69	31	50	50	94.8	5.2
59	41	54	46	92	8.0

*Denotes that solid NaCl was added to the mixture, sufficient so that the resulting water phase was approximately 1 M in NaCl.

10

In the following examples optical purity is measured by Chiral HPLC.

Example 2

15

Purification of *S*-diol by precipitation of racemic diol free base

20

A solution of *S*-diol in acetonitrile (500 mL, *ca.* 50 – 55% w/w, *S*:*R* ratio 95.72:4.28) at room temperature was cooled with stirring to –14 °C. The mixture was seeded with almost-racemic diol (*S*:*R* ratio *ca.* 60:40) after every drop in temperature of 2 °C. After 16 hours the mixture was filtered, and the filter cake was dried. Analysis of the

filter cake indicated that the *S*:*R* ratio was 57.97:42.03. Analysis of the mother liquor indicated that the *S*:*R* ratio was 98.065:1.935.

Example 3

5

Purification of *S*-diol by precipitation of racemic diol free base

A solution of *S*-diol in acetonitrile (500 mL, *ca.* 50 – 55% w/w, *S*:*R* ratio 95.72:4.28) at room temperature was cooled with stirring to –10 °C with cooling at a rate of 1 °C/h. The mixture was seeded with almost-racemic diol (*S*:*R* ratio *ca.* 60:40) after every drop in temperature of 5 °C. After 40 hours at –10 °C the mixture was filtered, and the filter cake was dried. Analysis of the filter cake indicated that the *S*:*R* ratio was 59.19:40.81. Analysis of the mother liquor indicated that the *S*:*R* ratio was 98.52:1.48.

15

Example 4

Purification of *S*-diol by precipitation of racemic diol as the hydrochloride salt

20 General method:

A mixture of *R*- and *S*-diols (as defined in the table below) (1 g) was dissolved in toluene (10 mL). Aqueous hydrochloric acid solution (1.0 equivalent; concentration as defined in the table below) was added, and solid sodium chloride was added (enough so that the concentration of NaCl in the water was approximately 1 or 2 M; see table below). The mixture was stirred overnight, and filtered. The residue was dried to give crystals of racemic diol hydrochloride, contaminated by some *S*-diol hydrochloride. The mother liquor was basified with aqueous ammonia solution to pH > 9, and the toluene layer was separated. The aqueous layer was washed once more with toluene, and the combined toluene extracts were dried over magnesium sulfate and evaporated under reduced pressure to give mainly *S*-diol, contaminated with a small amount of *R*-diol. See table for details. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

30

Before Precipitation				After Precipitation			
Mixture of Isomers		Aqueous HCl Conc. (M)	Aqueous NaCl Conc. (M)	Precipitate (mixture of R and S-diols)		Oil after basification, separation and evaporation (enriched S- enantiomer)	
S%	R%			S%	R%	S%	R%
82.3	17.7	1.0	1.0	58.4	41.6	99.4	0.6
82.3	17.7	2.0	1.0	49.7	50.3	97.7	2.3
82.3	17.7	1.0	2.0	81.3	18.7	86.2	13.8
82.3	17.7	2.0	2.0	60.1	39.9	99.7	0.3

Example 5

5

Purification of S-diol by precipitation of racemic diol as *p*-toluenesulfonyl, methanesulfonyl or acetate salts

General method:

- 10 A mixture of *R*- and *S*-diols (as defined in the table below) (1 g) was dissolved in toluene or ether (10 mL; as described in the table below). Aqueous NaCl solution (1 M, 3 mL) was added. The acid (as defined in the table below) was added neat as a liquid. The mixture was stirred overnight, and filtered or decanted. The residue was dried to give an oil or a solid. The mother liquor was basified with aqueous ammonia
- 15 solution to pH > 9, and the toluene or ether layer was separated. The aqueous layer was washed once more with toluene or ether, and the combined organic extracts were dried over magnesium sulfate and evaporated under reduced pressure to give mainly a solid or an oil. See table for details. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

Before Precipitation				After Precipitation			
Mixture of Isomers		Solvent	Acid (equiv.)	Precipitate (mixture of R and S-diols)		Oil after basification, separation and evaporation (enriched S-enantiomer)	
S%	R%			S%	R%	S%	R%
82.3	17.7	Toluene	MsOH (1)	64.4	35.6	94.3	5.7
82.3	17.7	Toluene	MsOH (2)	48.2	51.8	90.0	10.0
82.3	17.7	Ether	MsOH (1)	62.9	37.1	91.0	9.0
82.3	17.7	Ether	MsOH (2)	55.1	44.9	89.3	10.7
82.3	17.7	Toluene	AcOH (1)	71.3	28.7	96.2	3.8
82.3	17.7	Toluene	AcOH (2)	65.9	34.1	94.8	5.2
82.3	17.7	Ether	AcOH (1)	65.0	35.0	91.6	8.4
82.3	17.7	Ether	AcOH (2)	65.7	34.3	87.2	12.8

Example 6

5

Purification of S-diol by precipitation of a racemic diol salt in the absence of water

General method:

- 10 A mixture of R- and S-diols (as defined in the table below) (1 g) was dissolved in toluene or ether (10 mL; as described in the table below). The acid (as defined in the table below) was added neat as a solid. The mixture was stirred overnight, and filtered. The residue was dried to give an oil or a solid. Water was added to the mother liquor, and the mother liquor was basified with aqueous ammonia solution to pH > 9,
- 15 and the toluene or ether layer was separated. The aqueous layer was washed once more with toluene or ether, and the combined organic extracts were dried over magnesium sulfate and evaporated under reduced pressure to give mainly a solid or an

oil. See table for details. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

Before Precipitation				After Precipitation			
Mixture of Isomers		Solvent	Acid (equiv.)	Precipitate (mixture of R and S-diols)		Oil after basification, separation and evaporation (enriched S-enantiomer)	
S%	R%			S%	R%	S%	R%
82.3	17.7	Toluene	TsOH (0.4)	54.9	45.1	90.9	8.1
82.3	17.7	Ether	TsOH (0.4)	57.4	42.6	98.1	7.9
82.3	17.7	Toluene	(CO ₂ H) ₂ (0.2)	78.4	21.6	93	7
82.3	17.7	Toluene	(CO ₂ H) ₂ (0.4)	72.1	27.8	99.97	0.03
82.3	17.7	Toluene	(CO ₂ H) ₂ (1)	82.2	17.8	99.6	0.4
82.3	17.7	Ether	(CO ₂ H) ₂ (0.2)	58.0	42.0	97.7	2.3
82.3	17.7	Ether	(CO ₂ H) ₂ (0.4)	55.4	44.6	98.4	1.6
82.3	17.7	Ether	(CO ₂ H) ₂ (1)	72.0	28.0	99.5	0.5

5

Example 7

Purification of S-diol by precipitation of a racemic diol salt in the absence of water using various solvents

10

General method:

A mixture of *R*- and *S*-diols (as defined in the table below) (1 g) was dissolved in a solvent (10 mL; as described in the table below). The acid (as defined in the table below) was added neat as a solid. The mixture was stirred overnight, and filtered or
5 decanted if a precipitate had formed. Where a precipitate had formed, the residue was dried to give an oil or a solid. The mother liquor was evaporated, and the residue was taken up in a mixture of ether and water. This mixture was basified with aqueous ammonia solution to pH > 9, and the ether layer was separated. The aqueous layer was washed once more with ether, and the combined ether extracts were dried over
10 magnesium sulfate and evaporated under reduced pressure to give mainly a solid or an oil. See table for details. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

Before Precipitation				After Precipitation			
Mixture of Isomers		Solvent	Acid (equiv.)	Precipitate (mixture of R and S-diols)		Oil after basification, separation and evaporation (enriched S-enantiomer)	
S%	R%			S%	R%	S%	R%
82.3	17.7	MeOH	TsOH (0.4)	No Precipitation			
82.3	17.7	MeOH	(CO ₂ H) ₂ (0.2)	No Precipitation			
82.3	17.7	IPA	TsOH (0.4)	51.5	48.5	91.6	8.4
82.3	17.7	IPA	(CO ₂ H) ₂ (0.2)	54.9	45.1	98.3	1.7
82.3	17.7	Acetonitrile	TsOH (0.4)	No Precipitation			
82.3	17.7	Acetonitrile	(CO ₂ H) ₂ (0.2)	57.2	42.8	97.2	2.8
82.3	17.7	THF	TsOH (0.4)	No Precipitation			
82.3	17.7	THF	(CO ₂ H) ₂ (0.2)	53.2	46.8	98.9	1.1
82.3	17.7	Acetone	TsOH (0.4)	No Precipitation			
82.3	17.7	Acetone	(CO ₂ H) ₂ (0.2)	56.7	43.3	98.2	1.8
82.3	17.7	MIBK	TsOH (0.4)	56.8	43.2	98.5	1.5
82.3	17.7	MIBK	(CO ₂ H) ₂ (0.2)	58.7	41.3	99.6	0.4

Example 8

5

Purification of S-diol by precipitation of racemic diol oxalate

General method:

A mixture of *R*- and *S*-diols (as defined in the table below) (1 g) was dissolved in toluene (10 mL). An aqueous solution of NaCl was added (1 M, 3 mL) and oxalic acid (as defined in the table below) was added neat as a solid. The mixture was stirred overnight, and filtered or decanted if a precipitate had formed. Where a precipitate had formed, the residue was dried to give an oil or a solid. The mother liquor was basified with aqueous ammonia solution to pH > 9, and the toluene layer was separated. The aqueous layer was washed once more with toluene, and the combined toluene extracts were dried over magnesium sulfate and evaporated under reduced pressure to give mainly a solid or an oil. See table for details. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

Before Precipitation			After Precipitation			
Mixture of Isomers		Oxalic Acid (equiv.)	Precipitate (mixture of <i>R</i> and <i>S</i> -diols)		Oil after basification, separation and evaporation (enriched <i>S</i> -enantiomer)	
S%	R%		S%	R%	S%	R%
82.3	17.7	0.2	51.8	48.2	98.5	1.5
82.3	17.7	0.4	62.6	37.4	99.8	0.2
82.3	17.7	1.0	58.6	41.4	97.0	3.0
82.3	17.7	2.0	56.7	43.3	92.7	7.3

15

Example 9**Purification of *S*-diol by precipitation of racemic diol hydrochloride in water**20 **General method:**

A mixture of *R*- and *S*-diols (as defined in the table below) (1 g) was stirred with an aqueous solution of HCl (1 equivalent; see table for concentration). The mixture was stirred overnight, and sufficient NaCl was added (as a solid) so that the concentration of NaCl was 1 M. The mixture was filtered to give a solid. To the mother liquor was

added water and ether, was basified with aqueous ammonia solution to pH > 9, and the ether layer was separated. The aqueous layer was washed once more with ether, and the combined ether extracts were dried over magnesium sulfate and evaporated under reduced pressure to give mainly a solid or an oil. See table for details. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.

Before Precipitation			After Precipitation			
Mixture of Isomers		HCl conc. (M)	Precipitate (mixture of R and S-diols)		Oil after basification, separation and evaporation (enriched S-enantiomer)	
S%	R%		S%	R%	S%	R%
82.3	17.7	1	59.4	40.6	99.2	0.8
82.3	17.7	2	63.7	36.3	99.3	0.7

10 Example 10

Purification of S-diol by preferential dissolution of S-diol hydrochloride in water

General method:

15 A mixture of *R*- and *S*-diol hydrochloride salts (17.7 : 82.3; 5.5 g) was stirred with an aqueous solution of NaCl (1 M, 12 mL). The mixture was stirred overnight, and was filtered to give a solid. To the mother liquor was added water and ether, was basified with aqueous ammonia solution to pH > 9, and the ether layer was separated. The aqueous layer was washed once more with ether, and the combined ether extracts
20 were dried over magnesium sulfate and evaporated under reduced pressure to give mainly a solid or an oil. The residue from filtration contained *R*-diol and *S*-diol in a ratio of 1.0 : 99.0. The product from work-up of the filtrate contained *R*-diol and *S*-diol in a ratio of 38.8 : 61.2. Recovery of material was virtually quantitative, with the expected partitioning of weight between the respective samples.